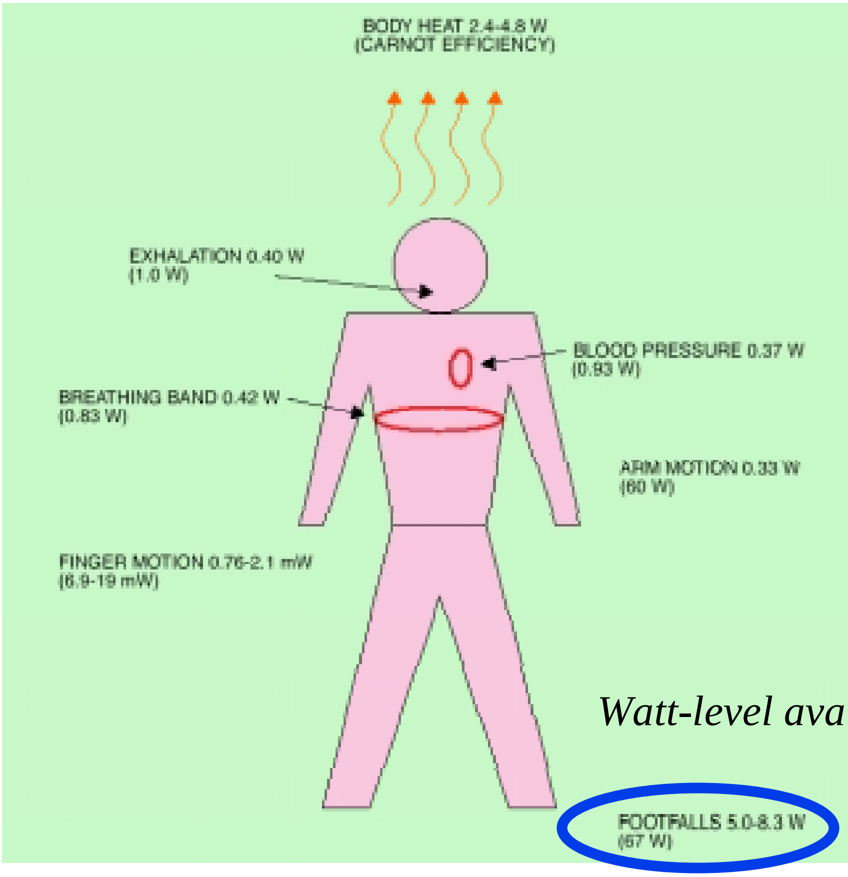
Parasitic Power Harvesting at the MIT Media Lab

- Shoe Scavenging
  - Piezoelectric insoles
  - Magnetics
- Applications…
  - On-Shoe
  - Off-Shoe

Joe Paradiso
Responsive Environments Group
www.media.mit.edu/resenv

DARPA 4/13

Power Insoles



Watt-level available

Thad Starner, ISJ 1997

Walking Powers Electronics

High-tech shoes harvesting old-fashioned foot power could someday generate enough electricity for portable phones and computers.

MIT scientists led by Joseph Paradiso, technical director of The Media Laboratory's Things That Work Consortium, have powered simple electronic identification tags with two different devices that resemble cushioned shoe inserts.

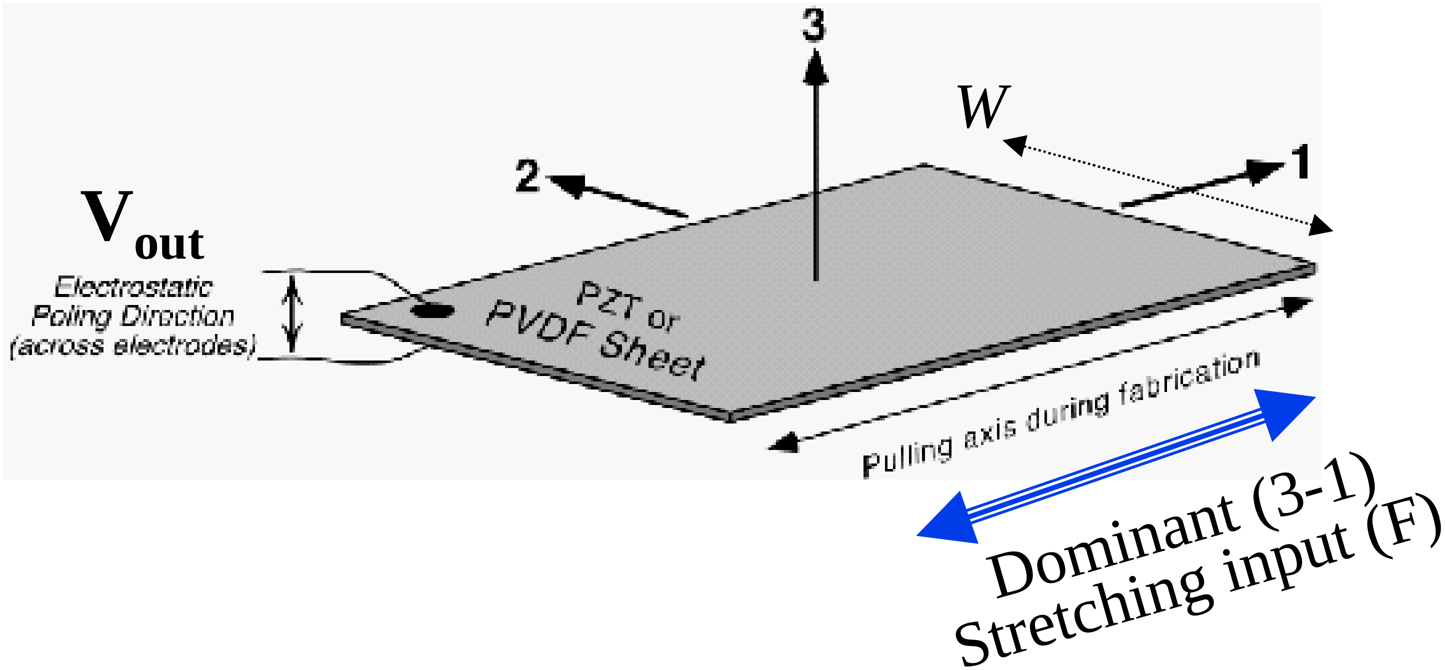
Both use the piezoelectric principle by which a physical distortion to a substance produces an electrical potential between its surfaces. One device harvests heel strikes' energy with a stiff piezoceramic material. The other device turns the flex in a sneaker's insole into electric power via a multilayered laminate of piezoelectric foil.

Power is measured in milliwatts. With a potential yield of 67 watts, researchers have room for improvement.

Pressure at the heel and bending at the insole (see inset) can power an electronic ankle ID tag.

Results presented at the Second International IEEE Conference on Wearable Computing, Pittsburgh PA October 1998

Piezoelectrics

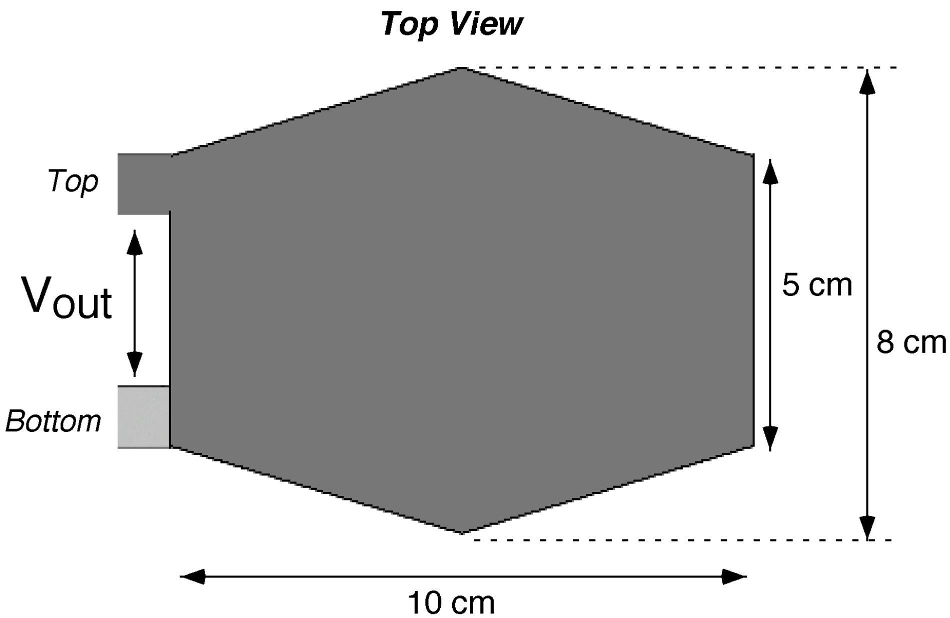


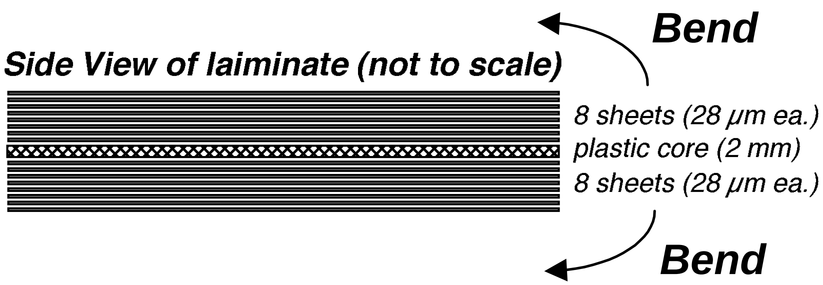
Piezoelectric materials respond mainly to tension and compression along their pulling (1) axis

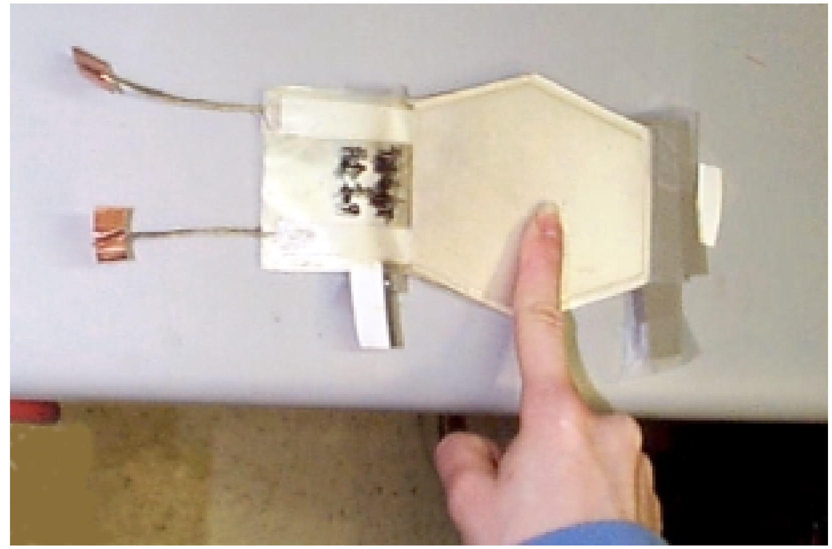
$$V_{out} = g_{31}\,\frac{F}{W}$$

Piezoelectric Voltage Constant (Mechanical-to-Electrical conversion)

The PVDF Stave







PVDF = Polyvinylidineflouride

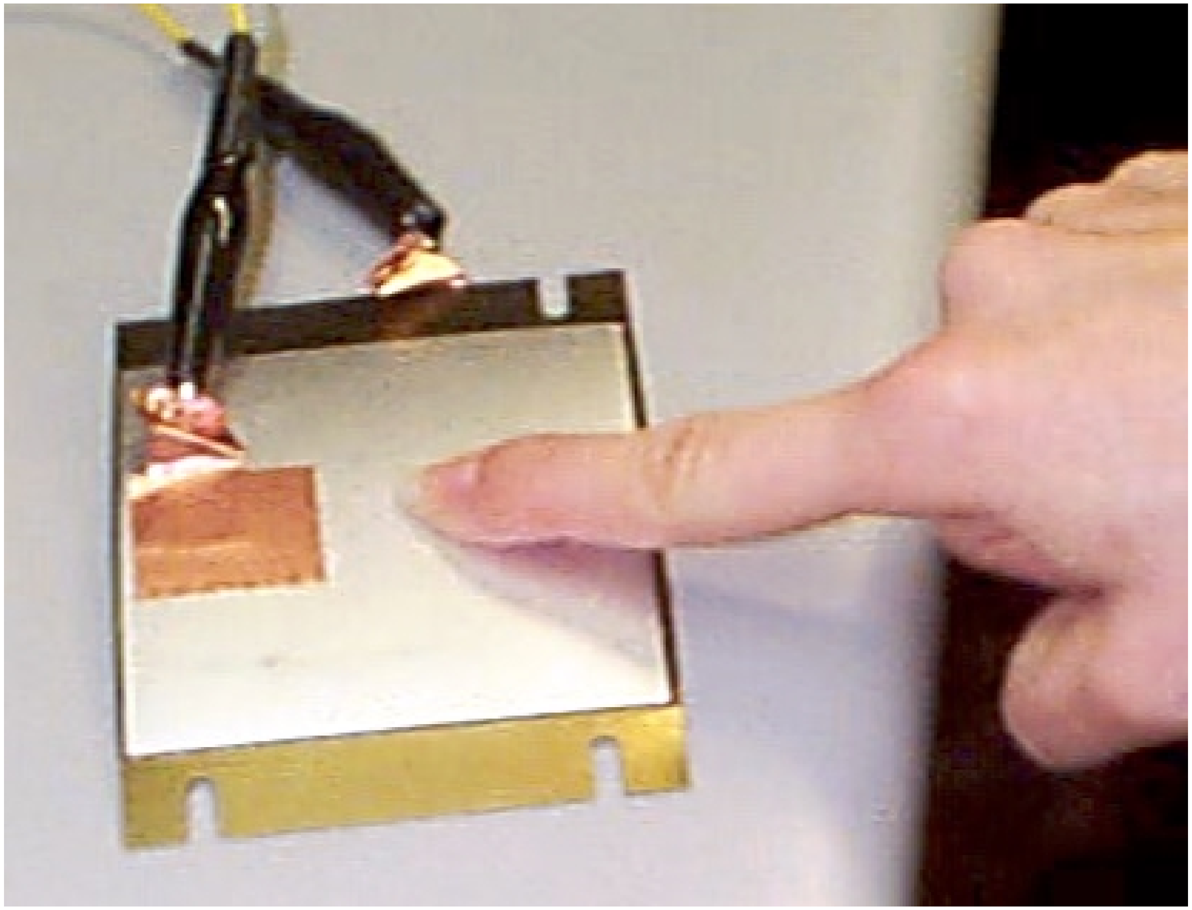
Piezoelectric Film material

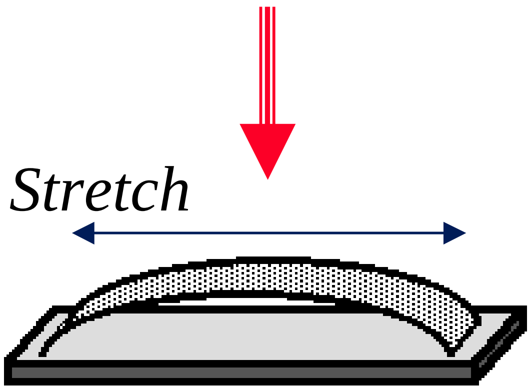
8 layers of PVDF foil laminated on both sides of 2 mm spacer

When bent, outer layers in expansion & inner in compression

Thanks to K. Park and M. Toda at AMP Sensors (now Measurement Specialties)

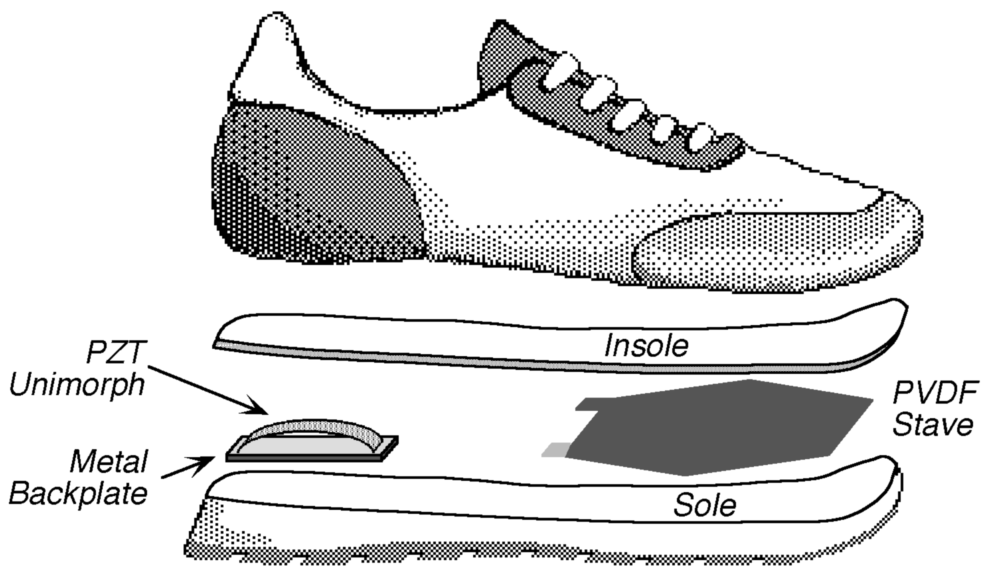
The PZT Unimorph

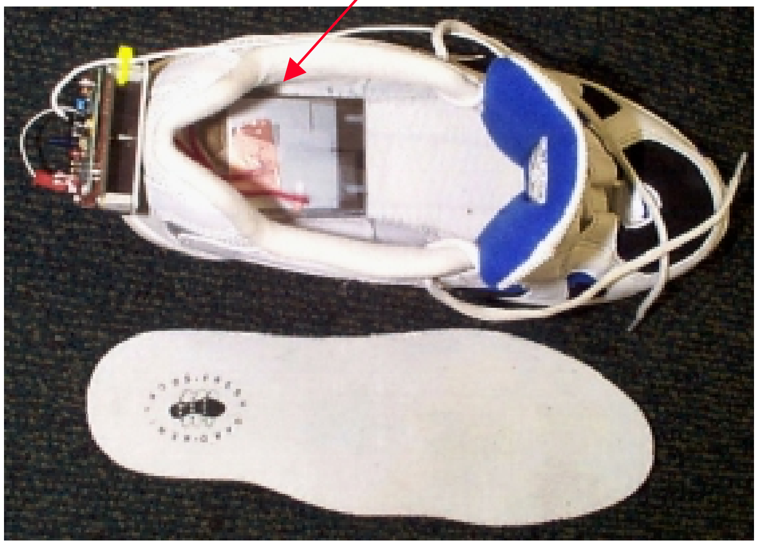




- Thunder™ sensor/actuator from Face Technology
  - PZT material integrated into semiflexable cloth matrix
  - Order of magnitude higher g_{31} than for PVDF
  - Generate voltage when pressed flat (break when reversed)

Integration into a Sneaker

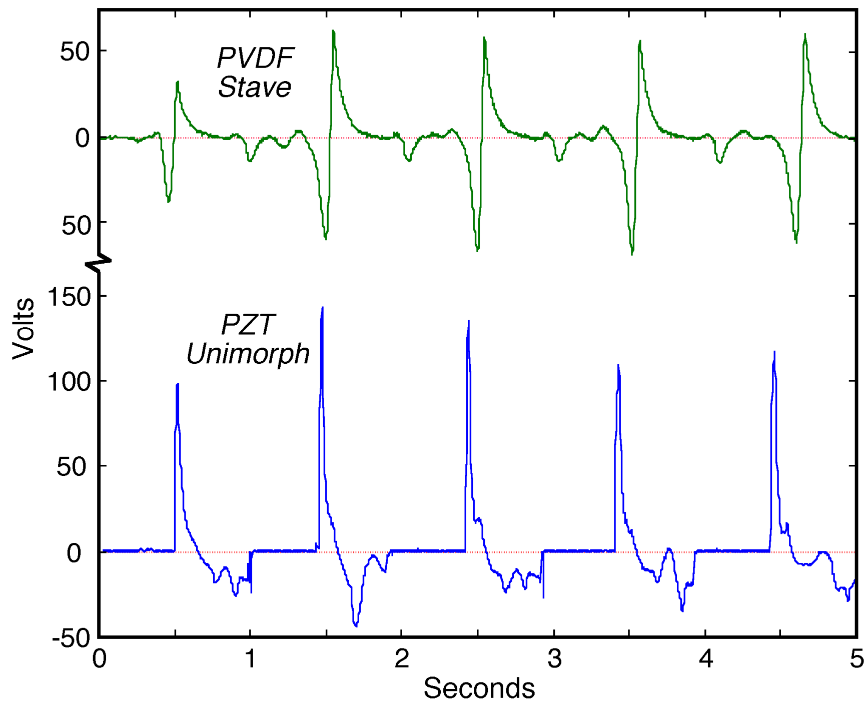




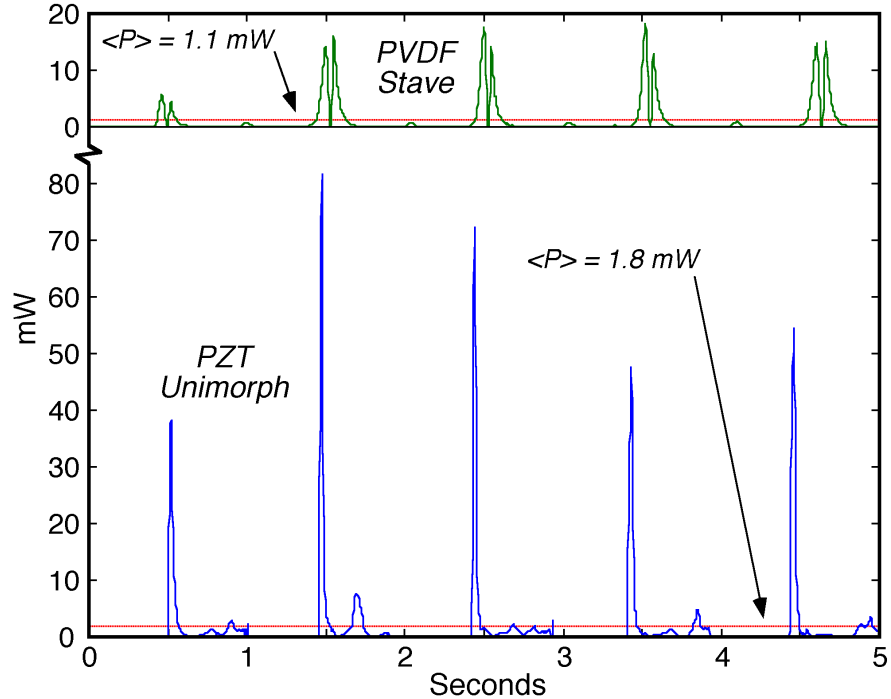
- Both elements easily hidden under insole
- Thunder Unimorph beneath heel
  - Maximize pressure
  - TH6R (5 x 5 cm, 15-mil PZT patch, 2.5 mm deflection)
- PVDF Stave under ball of foot
  - Maximize bending

Generated Power for the Piezos

Voltage into 250 KΩ load

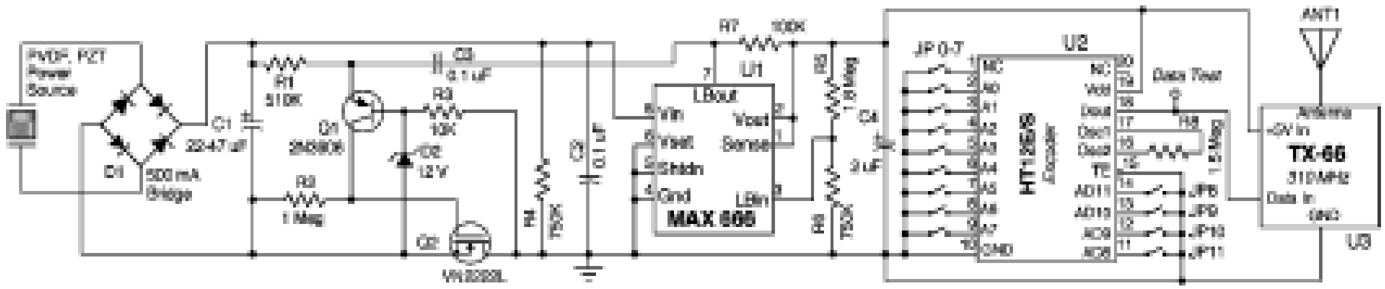


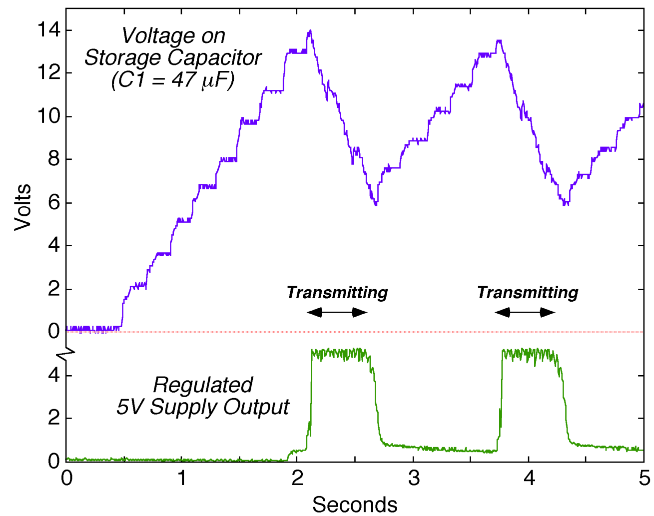
Delivered Power



- Standard “brisk” gait (1 Hz per foot)
- Wearer notices little perturbation to sneaker feel
- Piezos terminated at their efficient resistance (250KΩ)
  - For PVDF, $P_{peak} \cong 20$ mW, $\langle P \rangle \cong 1$ mW
  - For PZT, $P_{peak} \cong 80$ mW, $\langle P \rangle \cong 2$ mW

Application: Batteryless RFID Tag



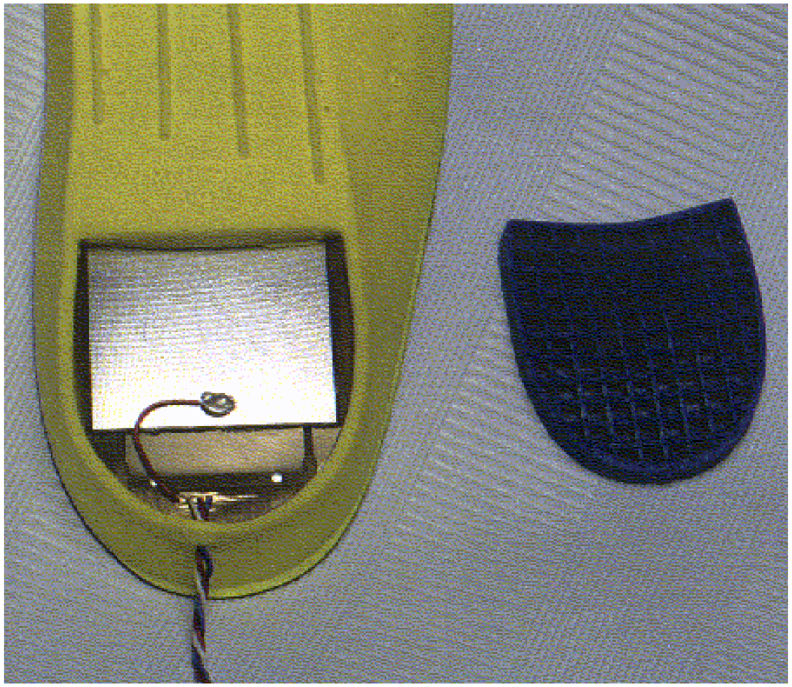


- Use Piezo-shoes to charge up capacitor after several steps
- When voltage surpasses 14 volts, activate 5 V regulator
  - Send 12-bit ID 6-7 times with 310 MHz ASK transmitter
- After 3-6 steps, we provide 3 mA for 0.5 sec
  - Capacitor back in charge mode after dropping below output

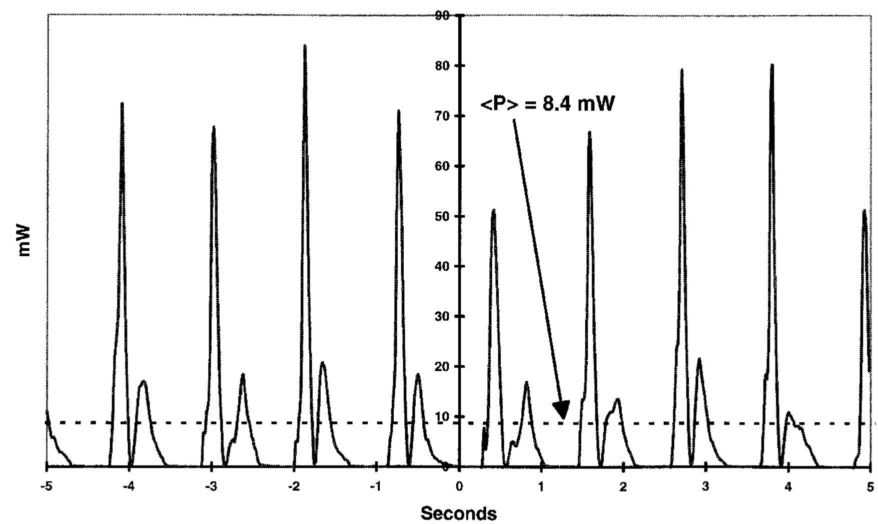
The Tagged Sneakers

Prototype power conditioning and tag transmitters

PZT Bimorph in an Navy Boot



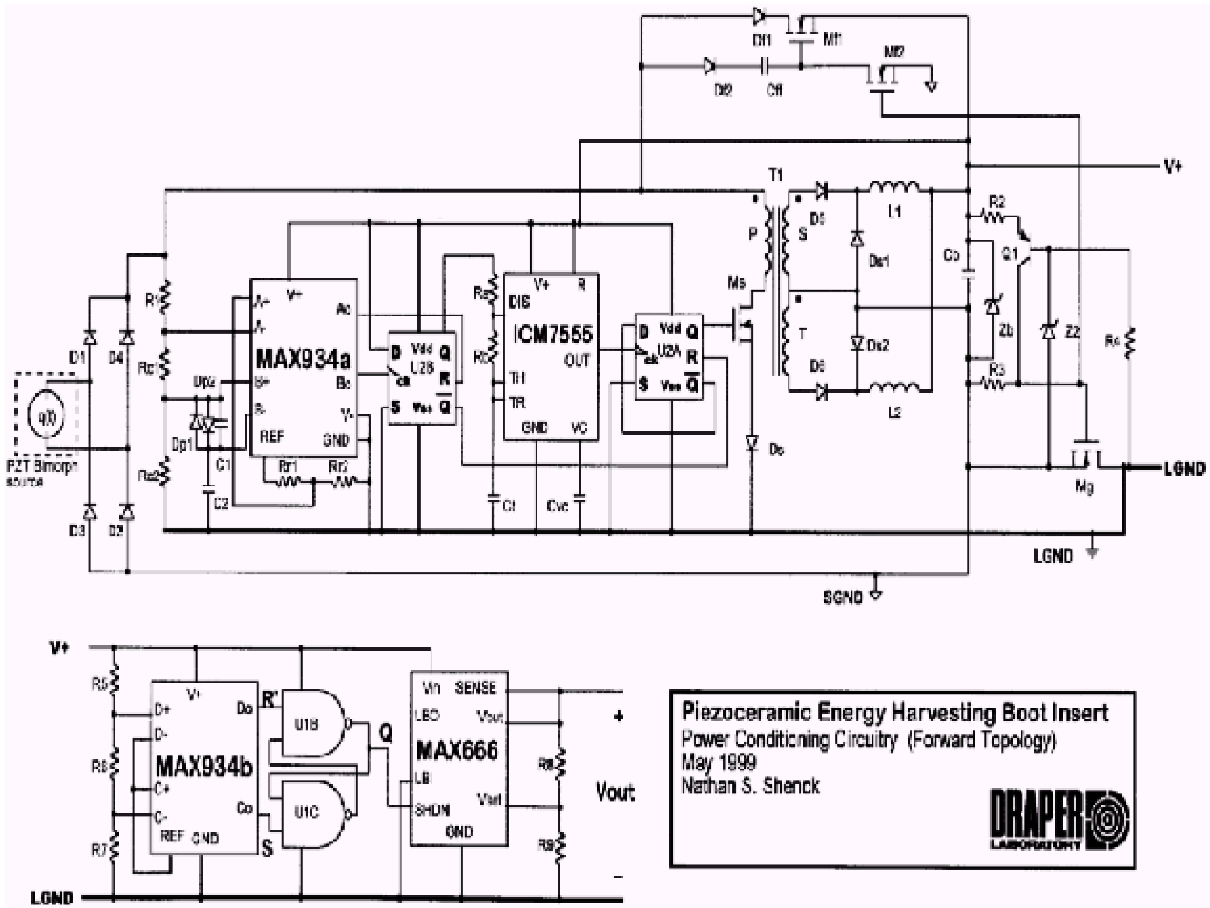
Power into 500 kOhm Resistive Load



- *Larger, bimorph device - raw power more than doubled.*
  - *Circa 20% efficient*

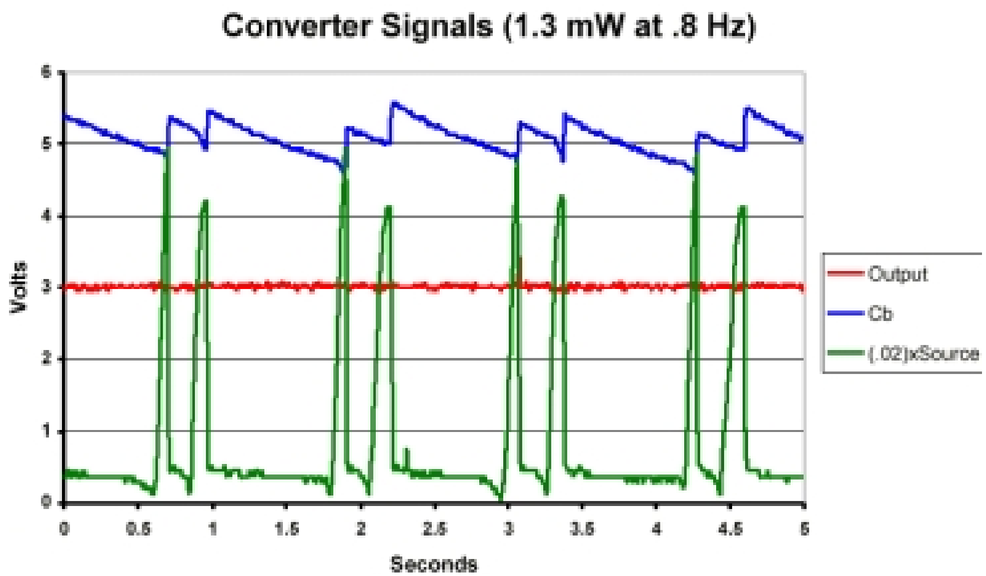
Nate Shenck - Draper Fellow and Media Lab Student

Nate’s Forward-Converting Switching Regulator



- Bootstraps via previous “bucket” circuit
- Switcher waits for peak charge before activating ($^1/_2\ CV^2$)
- High freq. (25 kHz) chop into transformer
  - No direct connection of bucket cap to piezo after bootstrap

Regulator performance



- Switcher drops ~100 V source down to ~5 V
- Subsequent low-power linear regulator gives stable 3 V
- Provides 1.3 mW of stable, regulated 3 V at 0.8 Hz walk
  - Converter is 20% efficient
  - Losses in transformer, MOSFET parasitics
  - More than twice as efficient as bucket scheme

Piezoelectric Insoles

- Convenient, as they have minimal shoe impact
- Not the best way to harness piezoelectrics
  - These systems seem to reach toward 10 mW
  - Inefficiency in changing compression to 3-1 pulling
  - Only one charge-pump cycle per footstrike
  - Nonresonant structures are used here
- Nesbit Hagood's system addresses these issues
  - Not all in the insole…
- Competition from embedded lithium battery
  - Embed a 3 V, 2A-Hr battery
    - Breakeven with piezo sole in circa 500 hours…
    - But then, you can recharge a battery at night...
- Other ways to bell the cat...

A Mechanical Solution...

Motor/Generators are 20% - over 90% efficient

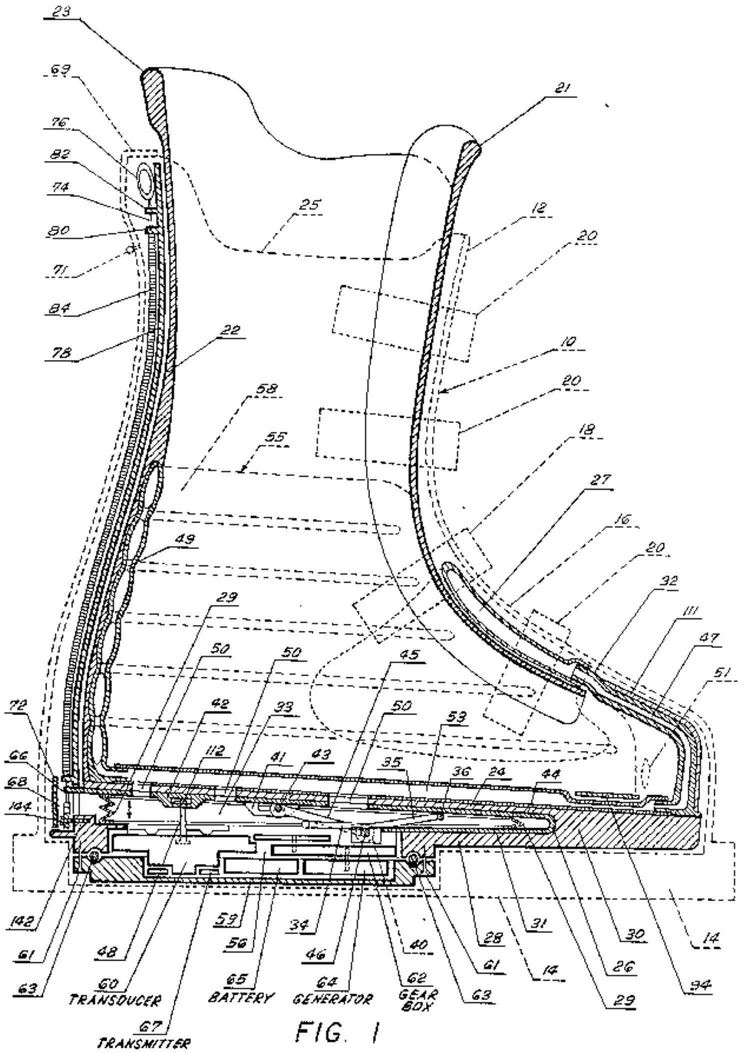


FIG. 1

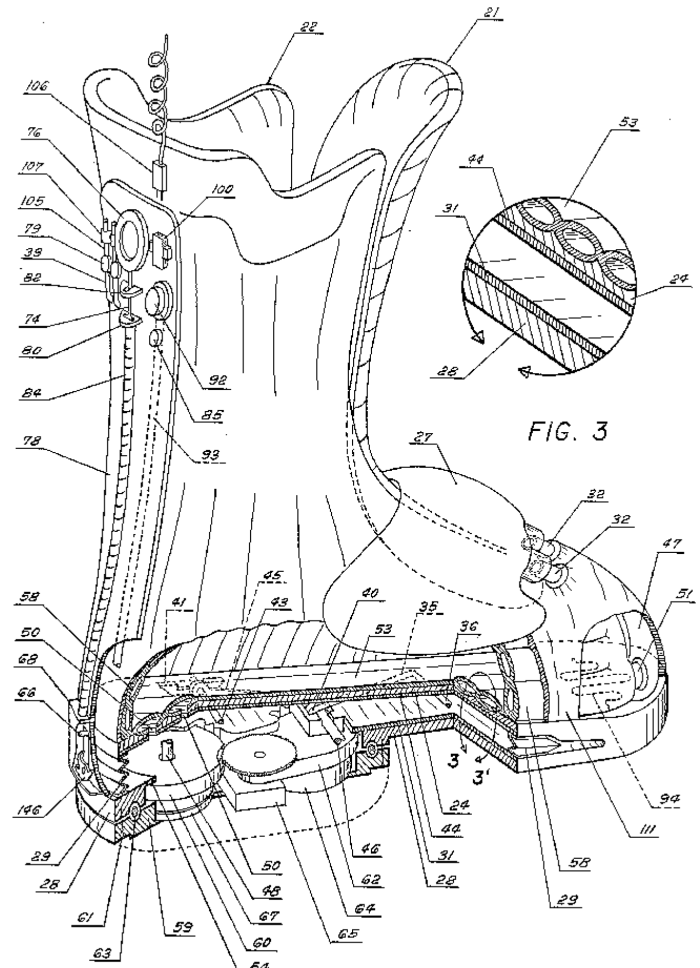


FIG. 2

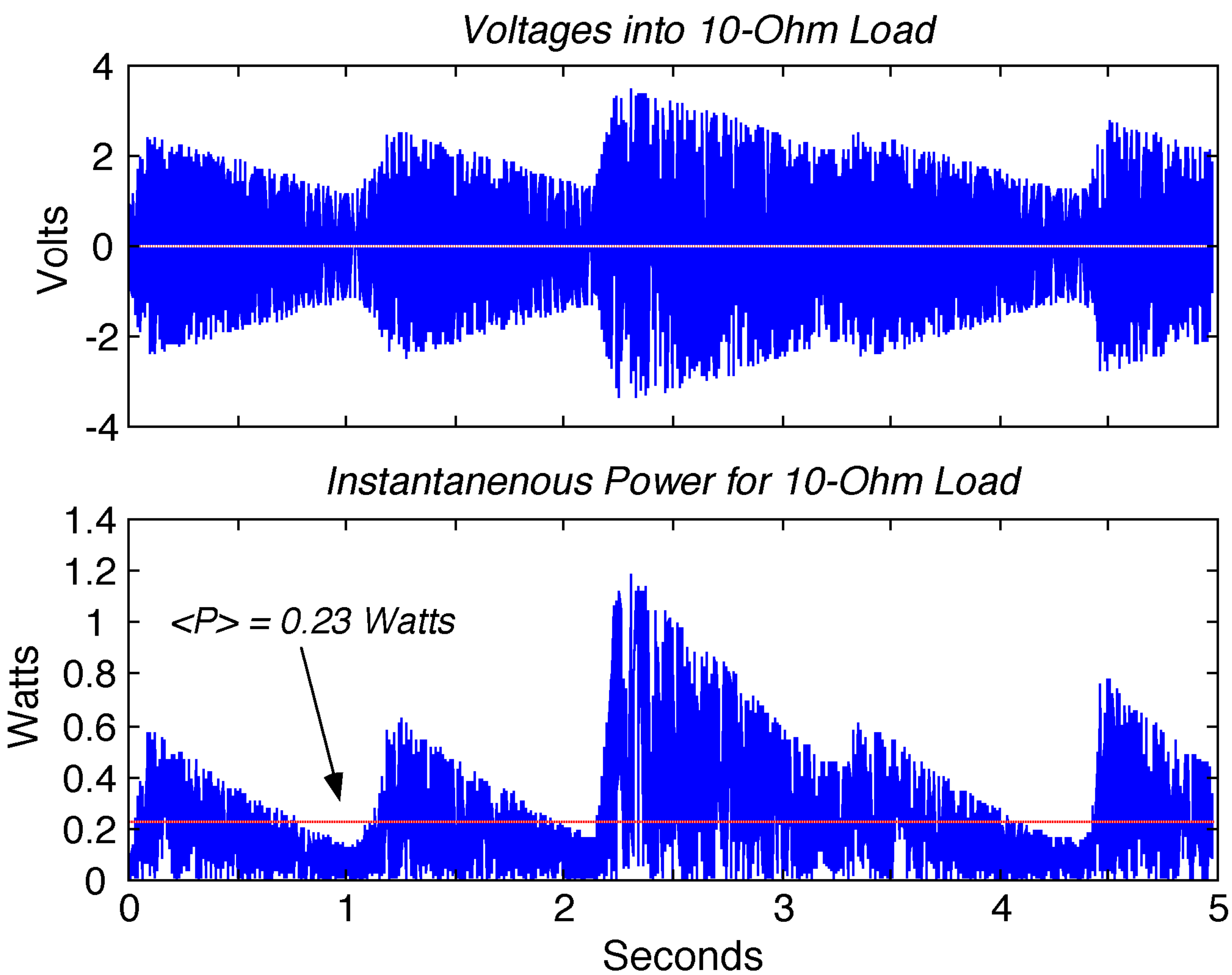
A parasitically-powered boot heater, US Patent 4845338, 1989

Rotary Magnetic Generator Retrofit

Attaches lever-driven flywheel/generator to shoe

- 3 cm deflection, bulky
- Suboptimal (e.g., better integration, hydraulics...)

Power from the Magnetic Generator



Produces a quarter watt average (≅ 1 W peak), but very obtrusive!